Bootheel lineament: A possible coseismic fault of the great New Madrid earthquakes

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ABSTRACT

A remote sensing examination of the New Madrid seismic zone has revealed a feature, the Bootheel lineament, that may be the surface expression of one of the coseismic faults of the great New Madrid earthquakes of 1811 and 1812. The lineament extends about 135 km in a north-northeast direction through northeastern Arkansas and southeastern Missouri. The morphology and pattern of the lineament suggest that it reflects a fault with strike-slip displacement. Field data indicate that liquefied sand was injected along the lineament, probably in 1811 and 1812. The Bootheel lineament does not coincide with any of the major arms of New Madrid seismicity, possibly indicating that the current seismicity does not precisely reflect the faults that ruptured in 1811 and 1812.

INTRODUCTION

The New Madrid seismic zone is the site of the largest historical earthquakes in eastern North America, the New Madrid earthquakes of 1811 and 1812 (Fuller, 1912; Nuttli, 1973; Penick, 1981; Johnston, 1982; Street and Nuttli, 1984). The sequence includes three earthquakes with estimated surface-wave magnitudes (M_S) greater than 8.0 (Nuttli, 1982; Nuttli and Herrmann, 1984), yet the surface expression of the causative fault(s) for these earthquakes has never been found. However, a comprehensive examination of the New Madrid seismic zone by means of satellite imagery (Marple, 1989; Marple and Schweig, 1991) reveals a discontinuous linear feature that may be the surface expression of one of the coseismic faults of the New Madrid earthquakes of 1811 and 1812 (Fig. 1). We have named this feature the Bootheel lineament. Identification and detailed studies of such possible seismogenic features are critical to analysis of regional seismic hazard in this poorly understood area.

The New Madrid seismic zone is in the northern part of the Mississippi embayment, a broad, south-southwest–plunging syncline whose axis coincides broadly with the Mississippi River. Embayment sedimentation has largely been controlled by eustatic changes in sea level and deformation of the Reelfoot rift, which formed in latest Precambrian and Early Cambrian time and has been intermittently active since then (Braile et al., 1982, 1984). Quaternary sedimentation and geomorphology of the region mostly reflect cyclic glacial and interglacial climates and associated glacial outwash (Saucier, 1974; Autin et al., 1991).

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The mapped trace of the Bootheel lineament is developed in a terrace of late Wisconsin–age braided-stream deposits (Saucier, 1974), several kilometres west of the Holocene flood plain of the modern meandering channel of the Mississippi River. Well records indicate that the total Quaternary section is between 50 and 80 m thick. Deposits in the late Wisconsin terrace are generally fine-grained clayey or silty sediments, 3 to 6 m thick, overlying clean sands and gravels. In this area the Mississippi River abandoned its braided terraces ca. 9.5 ka (Autin et al., 1991; Royall et al., 1991). Thus, the lineament is developed in sediments that are older than 9.5 ka, except for some deposits from small meandering streams in the area.

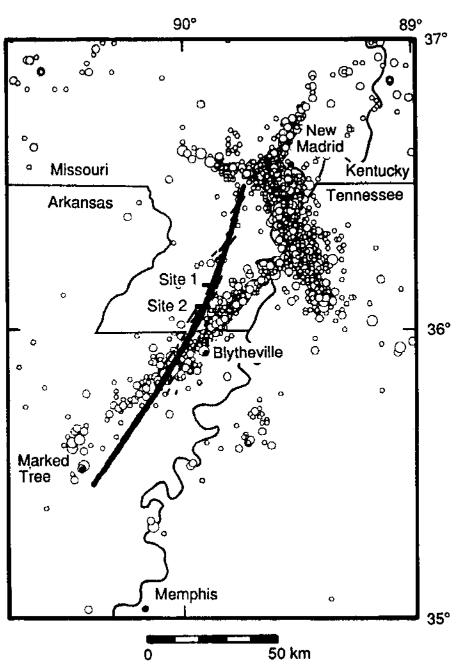

Figure 1. Bootheel lineament shown in relation to New Madrid seismic zone earthquakes (1974–1987). Thick gray line is lineament approximated from various satellite images. Shorter black lines are most prominent traces from aerial photography. Detailed mapping is in progress for southern part of lineament. Sites of two trenches are also shown.

BOOTHEEL LINEAMENT

The Bootheel lineament extends about 135 km from just east of Marked Tree, Arkansas, north-northeastward to west of New Madrid, Missouri. The lineament does not lie along any of the major trends in seismicity but cuts the southwestern arm of the seismic zone at a low angle near Blytheville, Arkansas (Fig. 1). With the exception of 11-km-long Reelfoot scarp in northwestern Tennessee, the Bootheel lineament is, to our knowledge, the first large-scale surface feature that may reflect deep-seated faulting rather than simply liquefaction-induced subsidence.

The nature of the trace of the Bootheel lineament varies along strike and is represented by some combination of (1) a constrast in sand-blow density on opposite sides, generally denser to the southeast; (2) shallow linear depressions, commonly containing standing water; (3) continuous or discontinuous linear bodies of sand; and (4) the apparent truncation of some fluvial features against the lineament on the southeast side (Fig. 2). Some discontinuities in the trace of the lineament separate linear segments with slightly different trends; other discontinuities are due to small stream-meander scars that obscure the lineament trace.

Detailed surveying of six profiles across the Bootheel lineament at two sites indicates the presence of a shallow depression 10 to 20 m wide (Fig. 3). At these two sites the area northwest of the lineament is about 0.5 to 1.0 m lower than the area to the southeast, although there is no consistent sense of elevation change along the

Figure 2. Aerial photograph of Bootheel lineament (between arrows) about 12 km southwest of Hayti, Missouri, showing location of trench site 1. Note contrasting sand-blow (white patches) density between two areas marked A, and apparent truncation of meander scars (B).

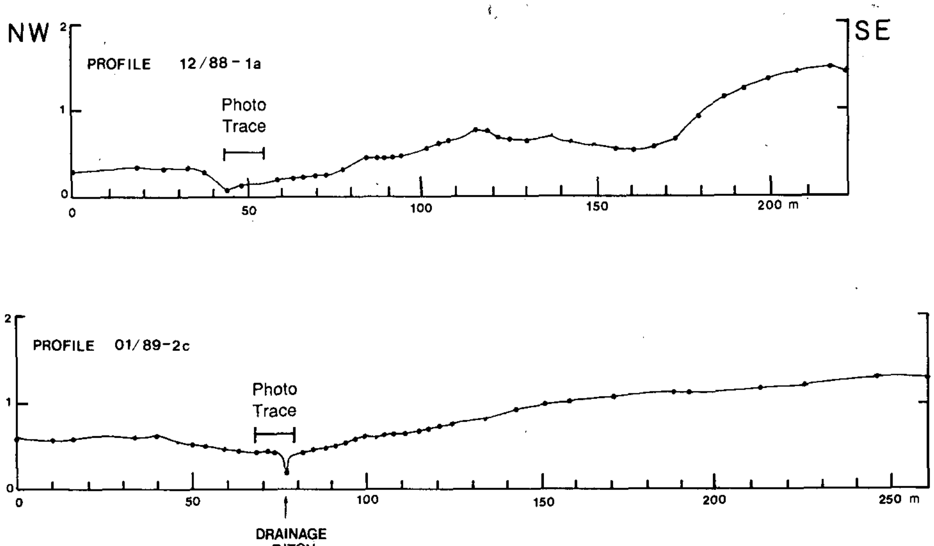

Figure 3. Two profiles across Bootheel lineament. Profile 12/88-1a was taken ~7.3 km north of trench site 1 (see Figs. 1 and 2). Profile 1/89-2c was measured at trench site 1. Vertical and horizontal scales in metres. Vertical exaggeration is 25×. Photo trace indicates location of trace of lineament on aerial photographs.

entire length of the lineament. In fact, in some areas the lineament has no noticeable topographic expression.

At several locations along the lineament, farmers have used the linear depression as drainage for their fields and as a boundary to separate acreage with different crops. Several farmers who have lived in the area since deforestation (about the 1920s) have stated that there used to be a bayou along some segments of the lineament and that the difference in elevation between the two sides was formerly more noticeable.

TRENCHING

We have excavated two trenches across the Bootheel lineament. Part of one trench log is shown in Figure 4A. A dike of liquefied sand, dipping 30° northwest in the south wall of the trench, underlies the surface sand body. On the north wall of the trench, the dike dips more steeply. The modern plow zone obscures any possible offset of the pre-1811 ground surface. In addition, the clayey sands into which the dike was intruded are massive; thus, there was no opportunity to observe offset horizontal bedding.

A second trench (Fig. 1) reveals two nearly vertical dikes of sand about 6 m apart along the mapped trace of the lineament (Fig. 4B). The block between the dikes has been down-dropped about 0.5 m, and the fissure left at the surface has been filled by the liquefied sand that erupted through the dikes. This down-dropped block may not be directly related to faulting, but it may have filled the space left by the erupted sand. In fact, this grabenlike structure is probably very local; the dikes are not parallel to each other in the trench, and if they are planar, they should intersect several metres south of the trench.

At the second trench site we found circumstantial evidence that supports lateral displacement along the lineament. The thickness of a sandy clay unit was greater within the graben than to either side of it. This could be due either to lateral movement that juxtaposed different thicknesses of the unit or to growth faulting that led to a greater rate of deposition within the graben. The latter explanation seems unlikely because there is no other sedimentologic or geomorphic evidence (such as a colluvial wedge or eroded graben shoulders) that a graben existed at this location before the last movement. Further trenching will help resolve this question.

AGE OF LATEST ACTIVITY ON THE BOOTHEEL LINEAMENT

Direct dating of earthquake features is very difficult in the New Madrid region because Eocene lignite is carried by all local streams and found throughout the Quaternary sediment record. Thus, the soil is contaminated by old carbon, making ^{14}C analysis of dispersed carbon problematic. A tree stump immediately below the surface buried by liquefied sand in the graben of the second trench and adjacent to one of the dikes, however, was radiometrically dated at 505 ±75 B.P. by means of ^{14}C analysis. (Note that the age is ^{13}C corrected: Geochron Laboratories, Cambridge, Massachusetts, sample GX-15839.) This wood predates the earthquake that liquefied the sand.

Geomorphically and pedologically, the liquefaction and offset documented in the two trenches appear to be very recent and most likely date from the 1811 and 1812 earthquakes. There is no evidence of sediment accumulation above the sand ejected onto the preliquefaction surface or of any significant soil development upon the liquefied sand. This liquefied sand appears to be identical to that found in sandblows throughout the epicentral region of the 1811 and 1812 earthquakes (Wesnousky et al., 1989). The prominent scarp at the first site, as well as elsewhere along the lineament, suggests youthfulness in this region of intense geomorphic processes. In addition, the anecdotal evidence that there was a bayou and higher scarp just 70 yr ago indicates that the disruption is recent enough to be geomorphically unstable and susceptible to rapid degradation. If the scarp had been more than a few hundred years old, such significant changes would probably not be expected. A similar argument was used by Jibson and Keefer (1988) to argue that landslides in the bluffs of the Misisipppi River east of the New Madrid seismic zone date from 1811 and 1812. All of the above data are compatible with our interpretation that the most recent tectonic activity on

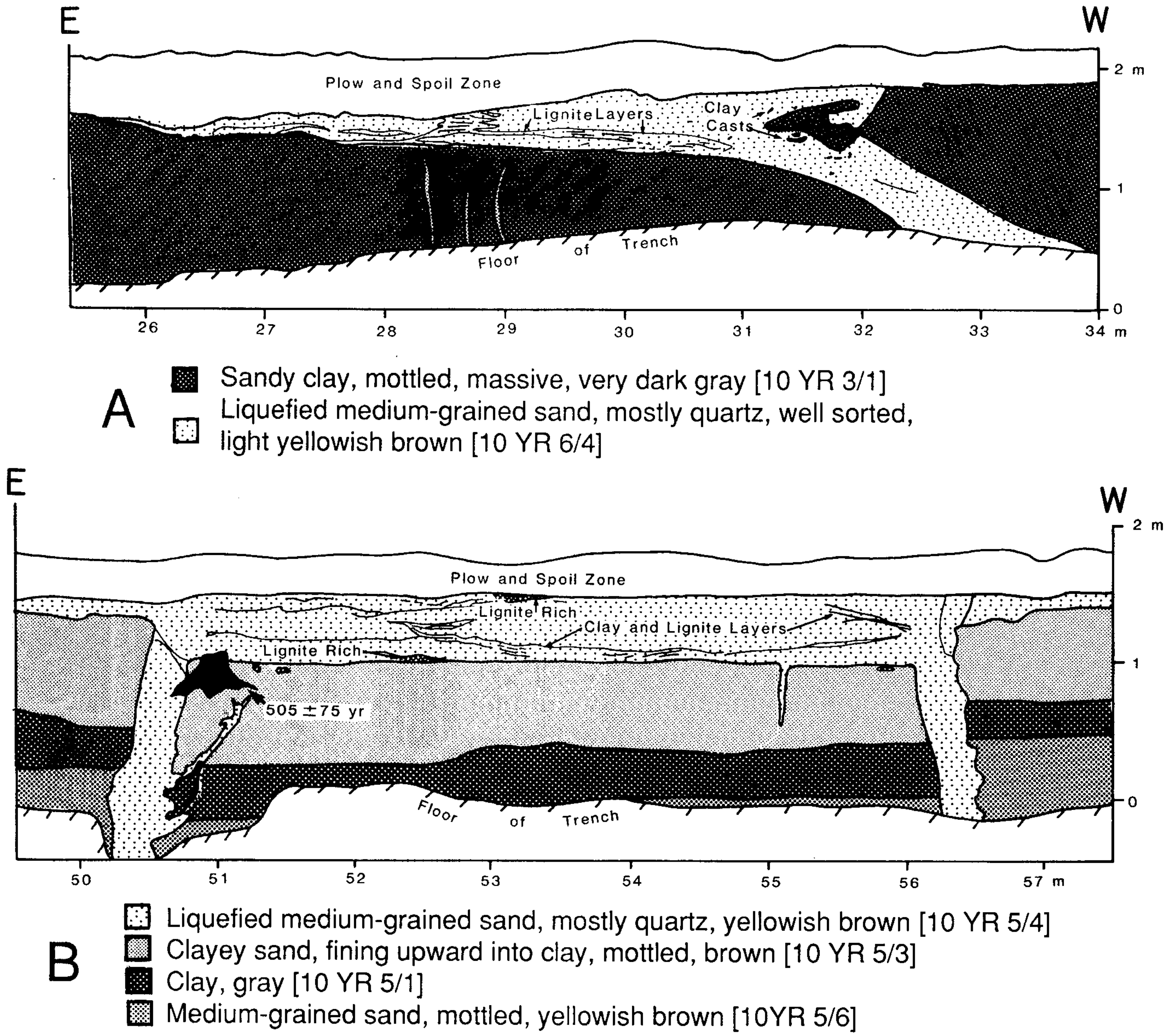

Figure 4. Logs of parts of trenches across Bootheel lineament (see Fig. 1 for locations); both cross areas where lineament is well defined by linear sand bodies. Horizontal scale shows distance from east end of each trench. A: Trench site 1. Lineament is expressed as shallow depression, area to northwest being about 0.5 m lower in elevation than area to southeast. Dike of sand underlies trace of lineament as identified from aerial photographs. B: Trench site 2. At this site there is no topographic expression. Down-dropped block between two sand dikes underlies trace of lineament. Note that clay unit (second from bottom) appears to have different thicknesses on opposite sides of dikes. Black in upper left is dated tree stump.

the lineament does, indeed, date from 1811 and 1812.

DISCUSSION AND CONCLUSIONS

Although evidence of structural offset along the Bootheel lineament is still inconclusive, its great length, its morphology, and the fact that it separates areas having different surface characteristics all suggest that it is the surface expression of a fault and may be capable of generating a large earthquake. Regressions of rupture length vs. magnitude suggest that its linear dimension (~135 km) is sufficient to require at least one large earthquake (moment magnitude, M_W, about 7.6) for its formation (A. C. Johnston, 1990, written commun.; D. L. Wells, 1990, written commun.). The inconsistency in the sense of vertical offset of the surface and the remarkably straight trace of its segments strongly suggest that the Bootheel lineament is the trace of a strike-slip fault. Focal mechanisms in the New Madrid seismic zone indicate that strike-slip movement would be expected on a fault with this orientation (Herrmann and Canas, 1978; O'Connell et al., 1982).

Despite the above evidence for faulting, other possible mechanisms of formation of the lineament must be considered. The most plausible is that the lineament represents the edge of a former braided-stream channel or terrace. Although the lineament is located entirely within a braided-stream terrace, mapping by Saucier (1964) suggests that in one area it does approximate the western edge of four topographically indistinct remnants of an older braided-stream terrace, which he defined largely on the basis of its sandier soils. However, the lineament extends both north and south of these areas. In addition, the sandier soils are mostly the result of more intense liquefaction and could be interpreted as an indication of some type of ground-water barrier along the lineament, causing different liquefaction susceptibilities on opposite sides. It may also be true that the older terrace deposits are simply more susceptible to liquefaction or that faulting has controlled the location of terrace remnants by isolating them slightly above the surrounding area. The trenches did not resolve this controversy; the sediments in the subsurface were not noticeably different on either side of the lineament. Only unambiguous offset of features that cross the lineament can demonstrate conclusively that the lineament is indeed seismogenic and not sedimentologic in origin.

The Bootheel lineament does not lie along any of the major arms of New Madrid seismicity. This could indicate that current seismicity does not reflect the fault(s) that ruptured in 1811 and 1812, perhaps because the earthquakes resulted in release or major reorientation of stress on the fault system. An analogous situation may be the 1857 and 1906 segments of the San Andreas fault that currently show very little seismicity relative to other segments of the fault system.

Preliminary analysis of high-resolution seismic reflection data across the lineament (Schweig et al., 1990) indicates a zone of folded and disrupted reflectors at least as young as the top of the Tertiary section. Faulting, if present, is either broadly distributed or is largely strike slip, which would be difficult to resolve on vertical sections. Other seismic reflection data show that the lineament in part overlies the Blytheville arch, a mostly pre–Late Cretaceous anticlinal feature that underlies the southern axial trend of the New Madrid seismic zone (Hamilton and McKeown, 1988; Hamilton and Mooney, 1990).

The results obtained thus far are exciting, yet ambiguous. The Bootheel lineament has many of the charactristics of the surface trace of a strike-slip fault. At the very least we can be sure that liquefied sand erupted along a 135-km-long zone of fissures, probably in 1811 or 1812. However, conclusive proof of deep-seated faulting is still lacking. If the lineament is indeed a fault, determination of the magnitude of the most recent displacement along it will constrain models of earthquake source dimensions and displacements for the 1811–1812 earthquake sequence, as well as future events.

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